RAINFALL VARIABILITY IN GHANA DURING 1961-2005

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ABSTRACT
This study uses daily rainfall data for 40-45 years to investigate the extent and nature of variability in the onset, cessation, annual rainfall and length of the rainy season (LRS) over four stations in Ghana (Tamale, Kumasi, Axim and Accra). The study shows that generally, the early onset and late cessation dates that occurred in the 1960s and early 70s and which resulted in long rainy seasons almost everywhere in Ghana have now changed significantly, the onset occurring rather late with early cessation since the 1980s. However, cessation for Accra was late from the 90s resulting in slightly longer rainy season. Pentade series of annual rainfall and rainy days also show a significant downward trend at all the stations but particularly more so at Axim. All these have serious consequences for agricultural practices and water resources management, particularly for hydropower generation in the country. Classification of the annual rainfall into wet and dry years and consideration of moisture availability shows significant differences between years of abundant and deficient rainfall. It was found that wet (dry) years have early (late) onset and late (early) cessation resulting in longer (shorter) rainy season. Also, rainfall amount and length of the rainy season during dry years are reduced by about 50% and more than 30 days, respectively at all stations. In general, main rainfall begins about 2 months after the moisture influx has attained a maximum value over all stations. The study also shows that dry spells of 10 or more days between rain events occur more frequently in the southern parts of Ghana than the north.

INTRODUCTION
In Ghana, as in most parts of West Africa, preparation of farmlands, mobilization of seeds and crop choice, sowing and crop yield are highly dependent on reliable rainfall pattern. Furthermore, the major source of energy in Ghana is linked to hydropower production from the river Volta at Akosombo. Due to increasing population pressure, fallow periods have reduced and crop rotation declined, leading to loss of soil fertility and less food production per unit area of cultivated land. This is so in the face of highly variable climatic conditions (extremely dry years and highly variable onset and cessation dates of the rainy season) in recent decades (Oduro-Afriyie et al., 2006). These variable climatic conditions have led to unstable and unsustainable agricultural prac-
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Activities, inefficient water resource management in the area of industry, hydropower and other services which could result in famine and food insecurity. To understand the impact of the rainfall variability which is one of the key climate response factors in the region, it is very important to study the trends of onset, cessation dates, and the seasonal rainfall amount, a study which is crucial for developing early warning system prediction model.

The most critical period for seed germination and crop establishment is the first four weeks when favourable rainfall conditions are needed most. Hence, there is the need to define carefully the onset of the rainy season to enhance agricultural activities and water resource management. Though there is not a unique definition for the date of the onset of the rainy season, it can be defined from traditional to scientific techniques, depending on local meteorological conditions. Some definitions of the onset of the rainy season are:

- First occurrence of any specified rainfall amount (e.g. 20 mm) in one or two consecutive days with no dry spell of 10 days or more within the next 30 days (Stern et al., 1981). This definition is confirmed by the daily rainfall analysis of Stern et al. (1982).
- The first 10-day period with a minimum cumulative rainfall of 20 mm followed by a dry spell of less than 10 days (Fasheun, 1983).
- Omotosho et al., (2000) defined the onset to be the beginning of the first two rains totaling 20 mm or more within 7 days, followed by 2-3 weeks each with at least 50% of the weekly crop water requirement.

The inclusion of the crop-water requirement is very important for crop/seed germination and establishment as it guarantees adequate water supply to the crop. In this study, the definition of onset of rainy season in Omotosho et al. (2000) will be adopted.

Cessation date of the rainy season is defined as any day from 1st September (for stations north of 9°N) and 1st October (for stations south of 9°N) after which there are 21 or more consecutive days of rainfall less than 50% of the crop water requirement. Odekunle et al. (2005) defined the cessation as the period towards the end of the rainy season, when rainfall distribution may no longer sustain crop growth.

Cessation of the rainfall season is not as critical for plants growth as most plants can survive for several days with little or no rain since the soil moisture content is still high. Crop failure and therefore poor harvest may result if the cessation occurs early or dry spell between two rainfall events is prolonged. The natural vegetation of Ghana is closely related to the ecological zones. Five agro-ecological zones defined on the basis of climate, reflected by the natural vegetation and influenced by the soils are recognized in Ghana, Fig1. The zones are (1) Sudan savanna, (2) Guinea savanna, (3) Tropical forest, (4) Tropical rain forest and (5) Coastal grassland. The four stations, Tamale (9.3°N 0.18°W), Kumasi (6.4°N 1.35°W), Accra (5.3°N 0.10°W), and Axim (4.58°N 2.6°W) were chosen from all the ecological zones apart from the Sudan savanna.

Fig 1: Map of Ghana showing the ecological zones and locations of Tamale, Kumasi, Axim and Accra

DATA AND ANALYSIS

The main data used in this work are from the Ghana Meteorological Agency. They comprised of daily values of average temperature (T), mean sea level pressure (P) and relative humidity (RH) taken at 0600 and 1500h. The numbers of years of data are (1961-2004), (1961-2003), (1966-2004), and (1977-2004) for Tamale, Kumasi, Accra and Axim respectively. The synoptic data (P, T, RH) were used to obtain the equivalent potential temperature, $\theta_e$, and their saturation values, $\theta_{es}$, from which their anomalies ($\theta'_e$ and $\theta'_{es}$) were evaluated.

$$\theta_e = \theta \times \exp(L_c \times q/C_p \times T_v)$$

where $\theta$ = potential temperature, $L_c$ = latent heat of condensation, $q$= the specific humidity $q_s$ = saturation specific humidity, $C_p$ = specific heat for dry air at constant pressure and $T_v$ is the virtual temperature. Five-day (pentade) averages were then obtained for each month and time series of these were plotted. One of the most important uses of equivalent potential temperature is in the stability analysis. Obasi (1964) used it to study the atmospheric stability between the periods of maximum and minimum rainfall episodes at Ikeja while Adefolalu (1973) used it to study the ‘anomalous August weather’ in West Africa. More recent use of this parameter is the prediction of onset, cessation and seasonal rainfall by Omotosho et al. (2000), who explained its ability for monitoring changes in moisture availability and heat content of air over any tropical station. This approach has therefore been used to determine their influence on years of abundant and deficit rainfall.

Daily rainfall values for about 40 years for each station were used to determine the actual onset, (ORa) and cessation, (CRa) dates and also length of the rainy season.

RESULTS AND DISCUSSION

Fig 2(a)–(d) show the pentade variations in the departures of the onset, cessation and length of the rainy season as well as the annual rainfall at each station between 1961 and 2005.

Onset, Cessation and Length of rainy season

There is a general obvious pattern of variation in the date of onset of rainy season over the entire country (Fig 2(a)), 1961-1980 witnessed generally early onset by as much as 37 days over Accra, but about 20 days on the average. In contrast, the rains have been late since that year up to 2005 but by only about 8 days in the mean. However, the end of the rains (Fig 2(b))
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Fig 2(c): Pentad (5-year) mean length of the rainy season departures for the stations

Fig 2(d): Pentad (5-year) mean annual rainfall departures for the stations

does not have similar consistent variation over all stations. Rather surprisingly, Axim at the coast has a similar pattern to that of Tamale in the north, with late cessation from the 60s to the early 80s and an early stoppage of rainfall again from early 1980 to 2000. Accra, the other station near the coast as Axim has an opposite behaviour to that of the station. Despite the irregular pattern of the cessation, Fig 2(c) is more or less a mirror image of Fig 2(a) for all stations studied. The 20-year period 1961–1980 had generally longer rainy season while the second 20–year period (1981–2000) has shorter lengths of the rainy season. These results are in agreement with the conclusion of Sivakumar (1993) that an early onset almost always leads to a longer rainy season. Furthermore, the range of variability in the onset is larger than that in the cessation, making onset prediction a very important issue, Table 1 and Fig 2(d) are very interesting because they show that a longer rainy season does not necessarily translate to higher rainfall amount. This is clearly brought out during period 1971-1980.

Dry Spells

Given in Table 2 is the number of dry days (spells) between consecutive rain days at each of the four stations investigated. Following Omotosho (2007), a day is regarded as dry if rainfall is less than 1.0mm. Dry spells are very crucial factors in agricultural planning and practices and also hydropower generation. A long dry spell between rain events could be disastrous for crops and may lead to outright crop failure while hydropower generation, plan-

Table 1: Mean onset and cessation dates, annual rainfall amounts and their variability

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<th>Cessation</th>
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ning and distribution could become difficult. Hence, any study of rainfall variability is not complete without an investigation of dry spells. Some facts are clear from this table. First, dry spells of longer duration (³10 days) are found to increase from the north down to the coastal areas. This is particularly so for spells of more than 20 days. It is interesting to note that the maximum occurrence of such spells is once in a year except at Accra. It is hardly ever observed to occur at Tamale, north of 9°N. This type of long dry spell can therefore only be associated with the so-called Little Dry Season over West Africa (Hamilton and Archbold, 1945; Irele, 1962).

Classification into Wet and Dry years
A cursory look at the annual rainfall data shows high variability in the rainfall amounts. In order to investigate the reasons for this distribution, 3-4 decades of annual rainfall data at each station were classified into wet, dry and normal year according to Omotosho (1990; 2007) who defined a wet year, as any year with rainfall amount

$$R_w > LTM + 0.25(LTM)$$

and a dry year, as

$$R_d < LTM - 0.25(LTM)$$

where $LTM$ is the long term mean of the annual rainfall. A normal year, $R_n$, has rainfall given as $R_d < R_n < R_w$. These are given in Table 3. Analysis of mean onset, cessation dates and the annual amount of rainfall during wet and dry years are also shown in Table 4.

Table 3 shows that, at each station, there is almost as many wet as dry years and that the 1960s and early 70s were generally wet years. It is also clear from Table 4 that wet years have early onset and late cessation and vice versa for dry years. Significantly however, the annual rainfall during dry years is reduced by about 50% of the wet cases over all the stations. Also, the length of the rainy season is reduced by more than 30 days during the dry year at all the stations.

Role of moisture Availability
It has been shown above that there is a marked difference in the pattern of the rainfall factors (onset, cessation, LRS and amount of rainfall) during wet and dry years. This suggests a significant difference in the moisture availability during the two rainfall periods. Omotosho (2007) used the anomalies of both the zonal wind ($u'$) and specific humidity ($q'$) to show that during wet years, moisture build-up is strong, deep and rapid while it is weak, slow and shallow during dry years. In this study, the use of the equivalent potential temperature is employed for this exercise since it has been proved that $\theta_e' \approx q'$ (Omotosho et al., 2000).

In the wet year composite, the pre-rainy season moisture build-up ($\theta_{es}' - \theta_{es}$) at Tamale peaks in February (Fig 3(a)), reducing sharply by mid-March till the middle of the year. In sharp contrast during the dry years, the pre-season moisture deficit reaches a minimum in March, (Fig 3(b)). Consequently, rainfall amount for dry years is only about 50% of that for wet years.

Table 3: Classification into wet and dry rainfall years at each station

<table>
<thead>
<tr>
<th></th>
<th>Tamale</th>
<th>Kumasi</th>
<th>Axim</th>
<th>Accra</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963</td>
<td>Wet year</td>
<td>1963</td>
<td>Wet yr.</td>
<td>1968</td>
</tr>
<tr>
<td>1965</td>
<td>Wet year</td>
<td>1966</td>
<td>Wet yr.</td>
<td>1965</td>
</tr>
<tr>
<td>1968</td>
<td>Wet year</td>
<td>1968</td>
<td>Wet yr.</td>
<td>1968</td>
</tr>
<tr>
<td>2001</td>
<td>Dry year</td>
<td>2000</td>
<td>Dry year</td>
<td>1976</td>
</tr>
</tbody>
</table>
Kumasi, being at a more southerly location than Tamale, has its maximum pre-season moisture build-up in January Fig 4(a). The dry composite Fig 4(b) started with pre-season moisture inflow in December but by mid-January, the atmosphere became dry lasting several months and thereby affecting the amount of rains. Omotosho et al. (2000) obtained similar patterns for drought years 1973 and 1983 over Nigeria.

Due to lack of data for more wet years, the relationship between mean of ($\theta_e - \theta_{es}$) and monthly rainfall amount at Axim is studied by showing the one wet year for which data is available (1979). Axim is located in the southwestern corner of the country. For this station, Fig 5(a) moisture build-up for the wet case starts strongly from November and continues throughout most of the year although decreasing at times. However in the dry case (Fig 5(b)) an initial moisture build-up between December and January gave way to moisture deficit (dryness) in March (that is ($\theta_{es}' > \theta_e'$) and continued throughout most of the year. Again the rainfall is about half the wet year value.

The situation at Accra for the wet composites is very different from those at the other three stations. Here, the graph of the wet years, Fig 6 (a) is much like the dry case being characterized by ($\theta_{es}' > \theta_e'$) throughout the year. Accra therefore, has the lowest wet composite annual rainfall. The reason for the behaviour of the $\theta_e'$ and $\theta_{es}'$ is not yet known. The dry year composite depicted in Fig 6(b) shows the usual dry year pattern and consequent low rainfall – again about 50% of the wet year cases.
In general, the results show that proper rains of 100 mm or more begin (onset) about 2 months after maximum moisture build-up ($\theta'_e - \theta_{es}$)$_{\text{max}}$. This is consistent with the result of Omotosho and Abiodun (2007) who found this to be about 2.5 months after the start of the build-up. These results suggest the dependency of seasonal rainfall on pre-season moisture accumulation. It is clear from the results at all stations that, the higher the moisture build-up, the higher the annual rainfall amount.

CONCLUSION
This study examined first, the extent of variability in the onset, cessation, annual rainfall and length of the rainy season from 1961-2000 over four stations in Ghana.

Results show that, generally in Ghana, the early onset and late cessation dates that occurred in the 1960s and which resulted in long rainy seasons have changed significantly since the 1980s. Pentade series of annual rainfall and rainy days show significant reduction at all the
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stations and in particular at Axim since the 1980s. Variability in the onset is generally larger than the cessation and increase southwards. These variability and that of the annual rainfall as well as the length of the rainy season increase from the north to the south, and are smaller in the southwestern than the southeastern part of Ghana. When the annual rainfall data were analysed and classified into wet and dry years in accordance with Omotosho (2007), the results showed that generally, wet years have early onset and late cessation, hence longer rainy season while dry years have late onset and early cessation with shorter rainy season. Also, rainfall amount during dry years is about 50% of that for wet years because significant differences exist in the moisture inflow during years of abundant and deficient rainfall. Whiles \( \theta'_{\text{e}} > \theta'_{\text{es}} \) during wet years, the reverse are the case for the dry years. It is also found that the length of the rainy season is reduced by about 50 days during the dry years at Kumasi and by about 30 days at the other stations. This finding therefore forms the basis of the modelling for the annual rainfall prediction in another paper on rainfall in Ghana.

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REFERENCES


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